Fukushima Recovery Forum

New Solution for Fukushima *"Three-Body-Problem"*

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@ JETRO

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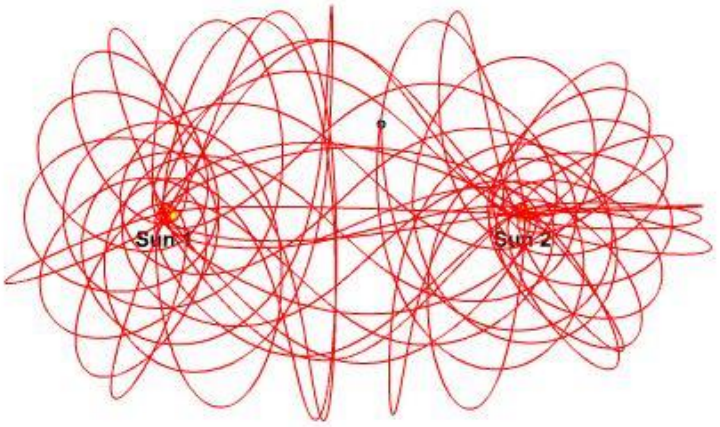
Our Approach

- **Three problems to be solved:**
  1. **Groundwater seepage into Rx. And Tb. Bldgs.**
  2. **Core debris long-term cooling**
  3. **Core debris retrieval**



- **Solution for "three-body-problem"**
  - **Three problems are not independent but interacting.**
  - **Three solutions for three individual problems may conflict each other.**
  - **An optimum set of solutions for three interacting problems is to be found.**
- **"Low-Tech" rather than "High-Tech"**
  - **An inovative combination of low-tech (proven) technologies.**
  - **Safer and less risky**

Classic Approach and Its Critical Technical Issues

- Groundwater seepage: Underground Frozen Fence
  - Proven technology and relatively reliable/cost-effective for short term.
  - When can we “turn off” the system?
  - “Tank Farm” is NOT under its protection coverage.
- Long-team cooling: Circulating water
  - Currently effective.
  - Difficult to isolate from groundwater seepage issue.
  - Never-ending carry-over of waterborne radioactivity from core debris.
- Core debris retrieval: Remote (underwater) tools
  - Conventionally applied for most previous decommissioning projects.
  - Radiologically harsh environment.
  - **Keeping structurally degraded containment flooded for long duration is a serious safety concern.**

Potential consequences of flooded containment failure

- **Radiological Safety**
  - **Potentially resulting in major uncontrolled airborne and waterborne releases of radioactive material to external environment.**
  - **Radiation exposure to site workers.**
- **Project Management**
  - **Major cost/schedule impacts for mitigation and recovery.**
- **Political, Psychological, and Socio-economical Impacts**
  - **Fukushima refugees: disappointment, fear, reluctance to return**
  - **Domestic: distrust of government (regulator) ability to control**
  - **International: Tokyo Olympic 2020 less attractive**
- **Leading another complicated "multi-body-problem"**

No.1 Priority = Public Safety

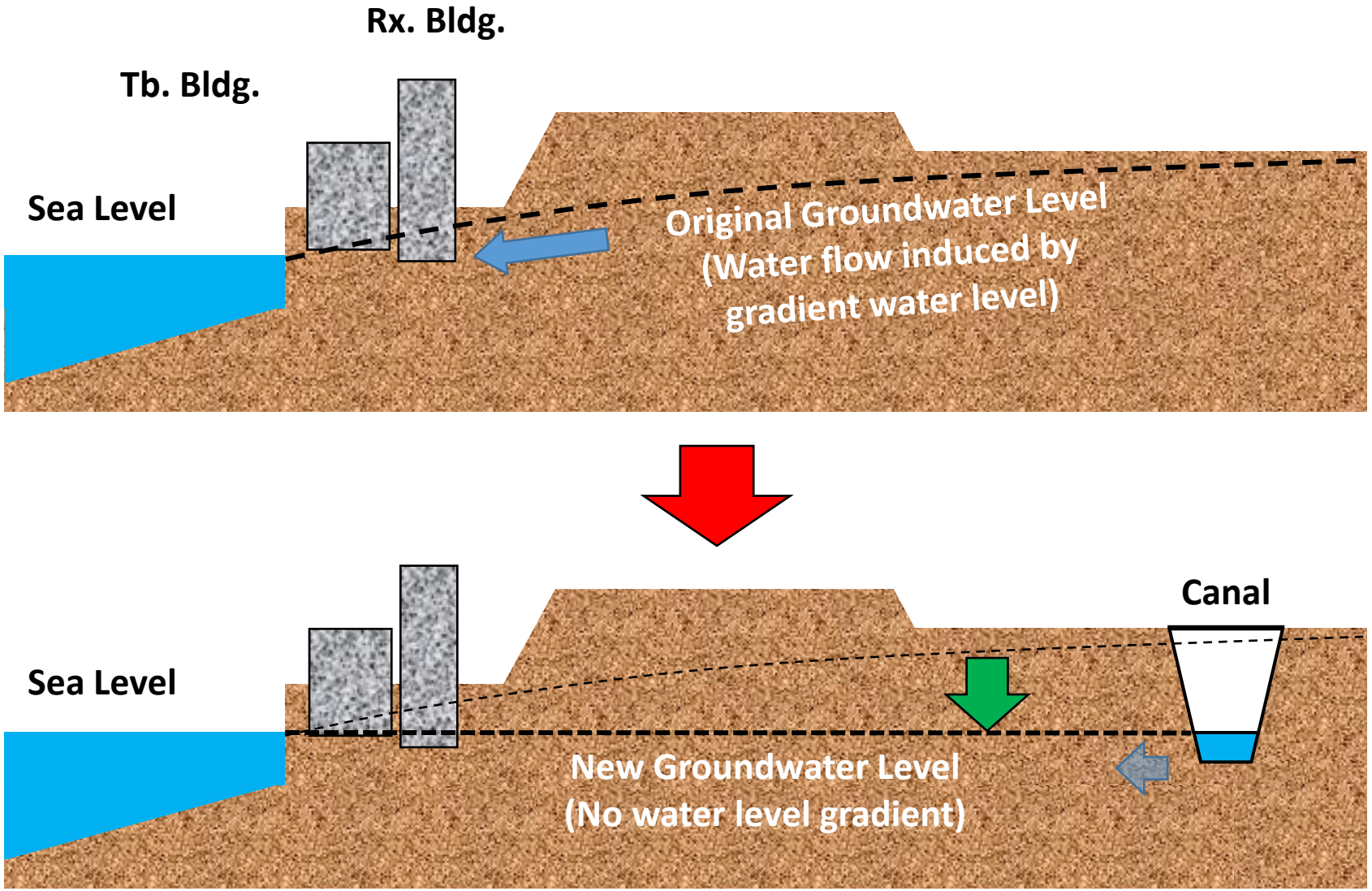
Potential safety risks of containment flooding

- **Mechanical, thermal, and chemical degradations of various "weak-points" of containment during accident evolution.**
  - **Exposed to elevated pressure/temperature condition, resulting in unanalyzed stress/strain conditions, potentially having created cracks and ruptures at various locations not accessible for inspection.**
  - **Containment is composed of many carbon steel plates with different thicknesses and contains hundreds of weld seams locally heat-treated. Original DBA-qualified corrosion-resistant coating was completely lost.**
  - **Large amount of seawater was injected, leaving the containment under corrosive environment.**
- **Degradation is progressive under poorly controlled environment.**
  - **Many past incidents suggest limited effectiveness of global environmental control to prevent local degradation.**
- **Unknown seismic resistance.**

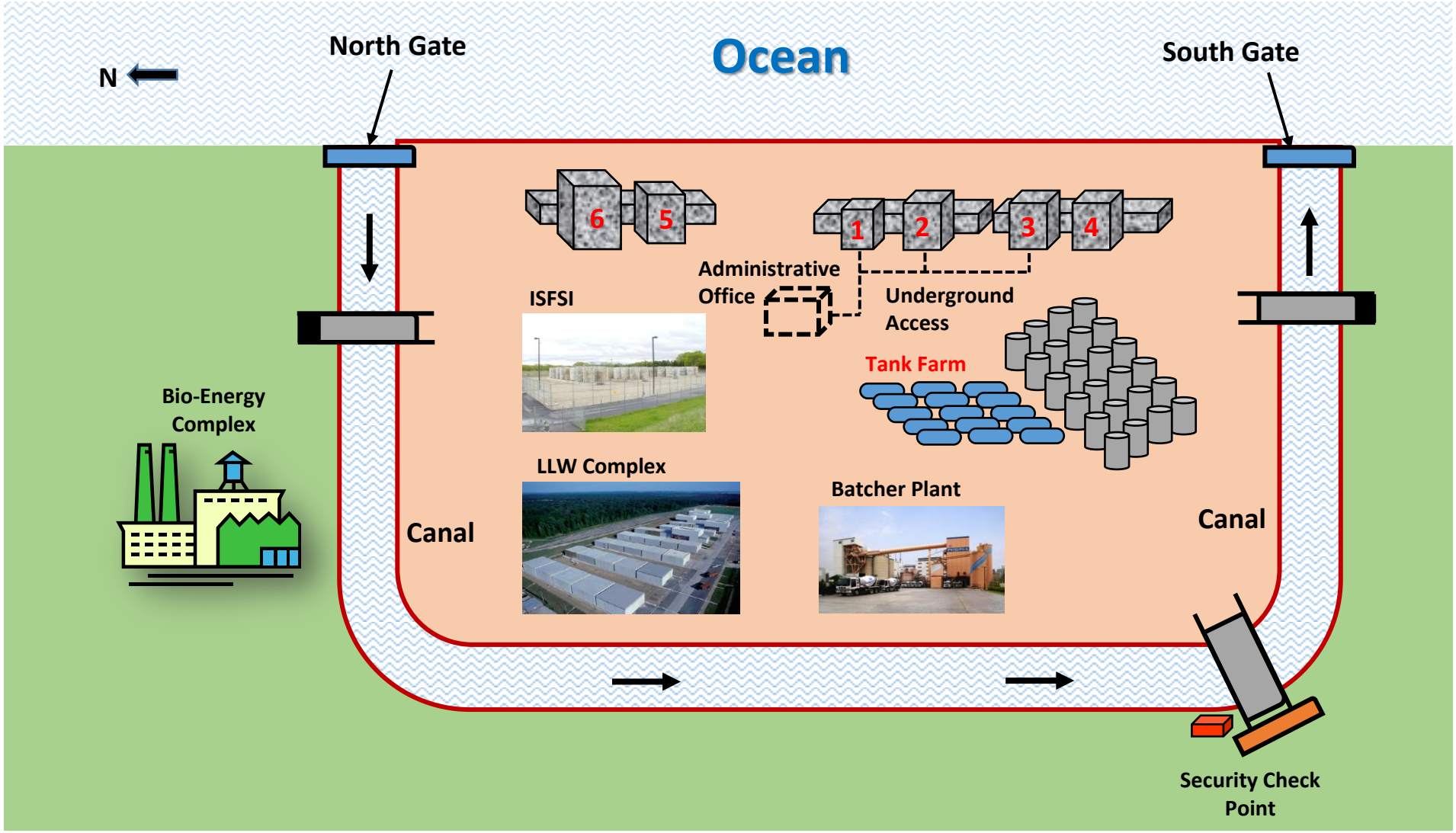
New Approach

- **Groundwater seepage:** **Canal**
  - **No water level gradient:** groundwater lever = seawater level
  - **Benefit of massive "dry-island":** LLW trench, "Sponge" to absorb spilled water in case of tank failure, underground administrative office
  - **Reliable security boundary:** Ideal for long-term spent fuel storage
  - **100% passive.**
- **Long-team cooling:** **Air-cooling**
  - **100 - 200kW is manageable heat load**
  - **Same concept as "Dry cask" for spent fuel storage**
  - **Heat dissipation by conduction, convection, and radiation**
- **Core debris retrieval:** **Hot-Cell, Robot Arm, Manipulator**
  - **Worker-friendly environment:** Robust solid (versus fluid) shielding
  - **NPT Compliance:** Better traceability of fission materials
  - **R&ID Opportunity:** Visual accessibility for detail in-vessel inspection to study extremely rare as-left severe accident conditions.

1. Canal and "Dry-Island"

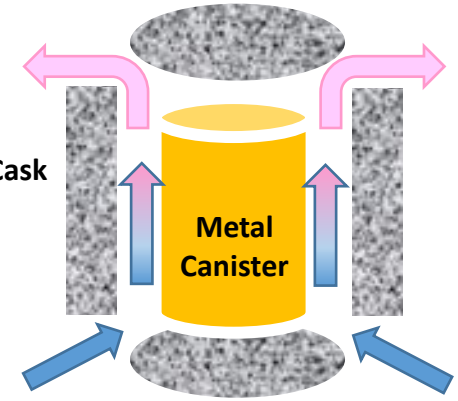


“Dry-Island”


N
North Gate
Ocean
South Gate
6
5
1
2
3
4
Administrative Office
Underground Access
ISFSI
Tank Farm
Bio-Energy Complex
LLW Complex
Batcher Plant
Canal
Canal
Security Check Point

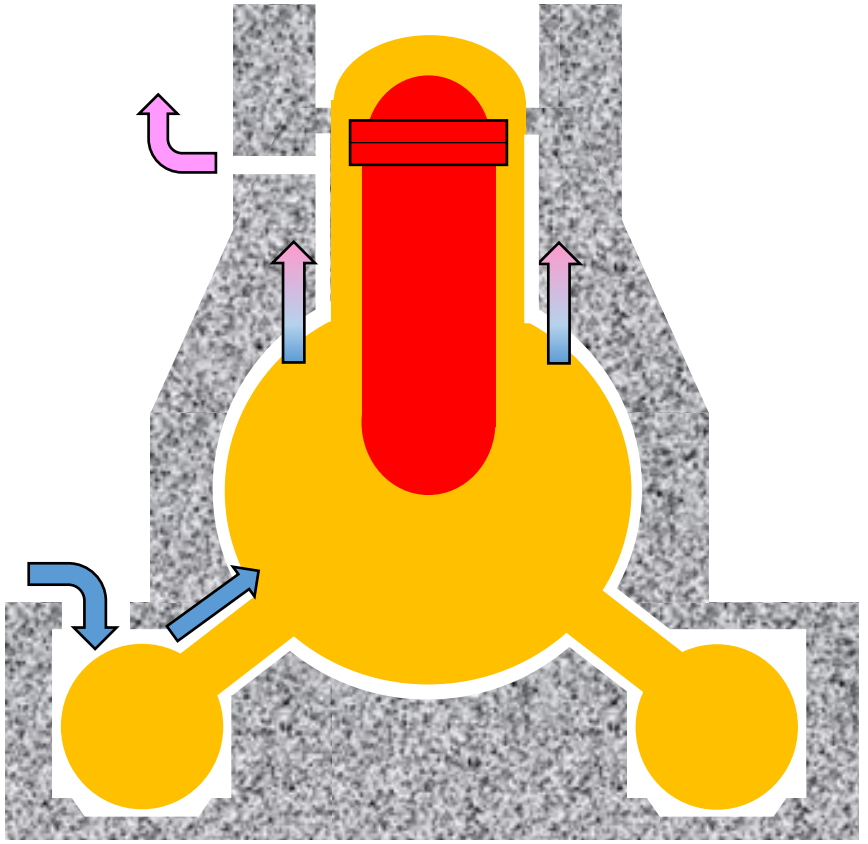
2. Air-Cooling

Spent Fuel Dry-Cask

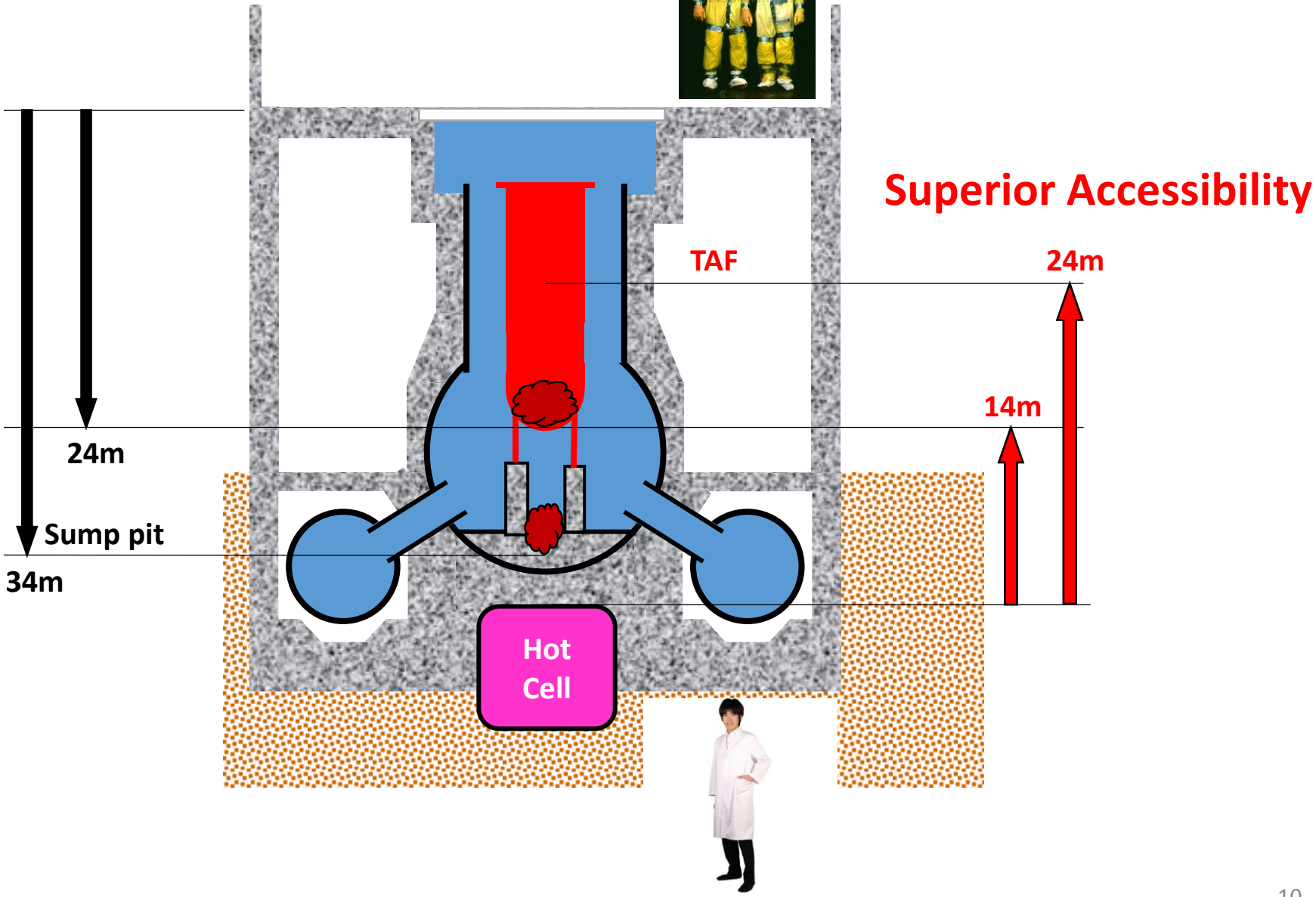


	Dry Cask (MAGNASTOR)	Containment Units 2/3
# of Fuel Bundles	87	548
Heat Load	33kW	200kW
Surface Area	27.7m^2	> 1,500m^2
Filled Gas	Helium @7atm	N2
Fuel Cladding Temp	(Est.) 361℃	Not specified
Containment Temp	(Est.) 222℃	?
Concrete Temp	(Est.) 67℃	?

Containment

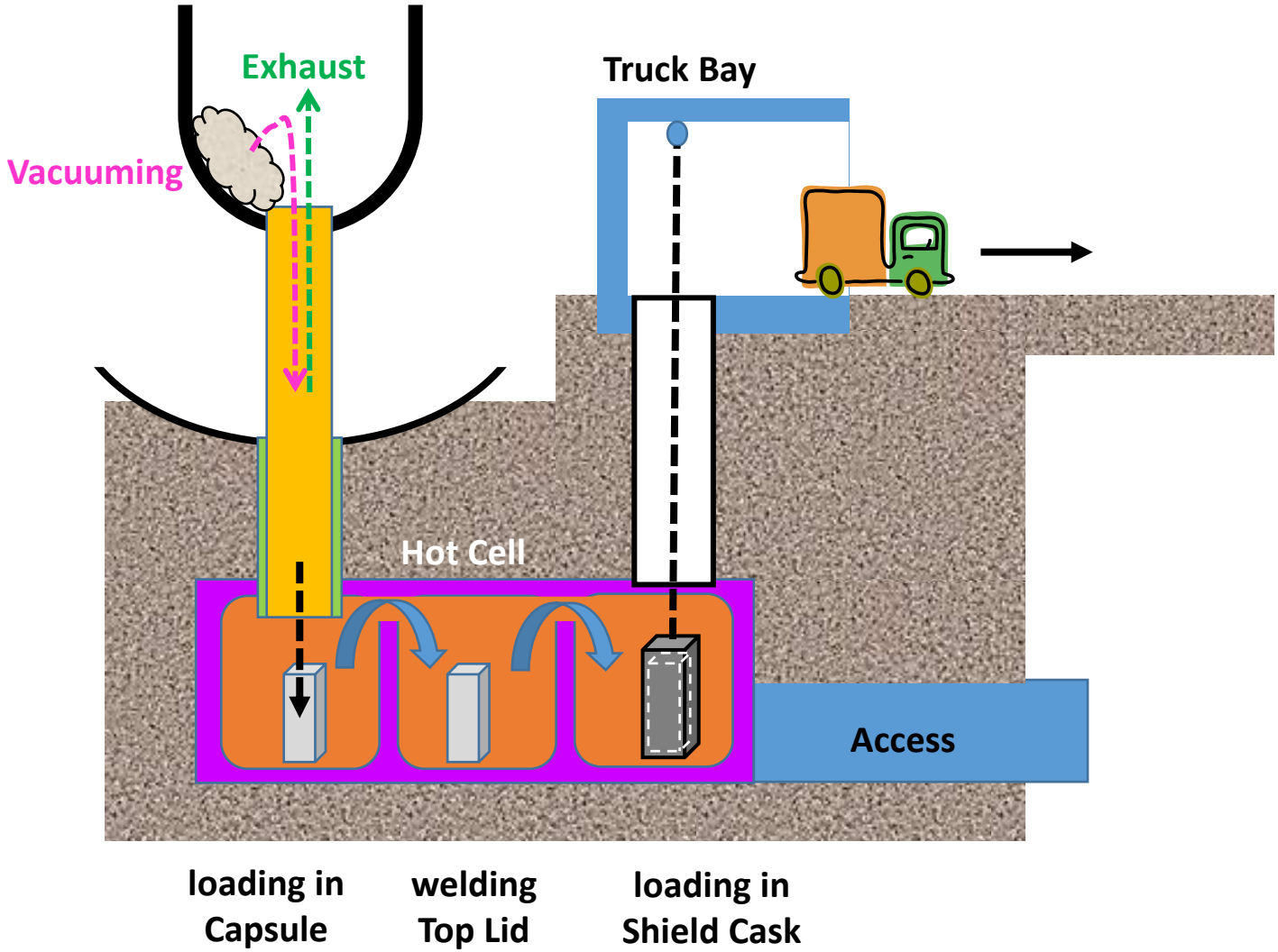


3. Hot Cell


Superior Accessibility
TAF
24m
14m
24m
Sump pit
34m
Hot
Cell

Robot Arm

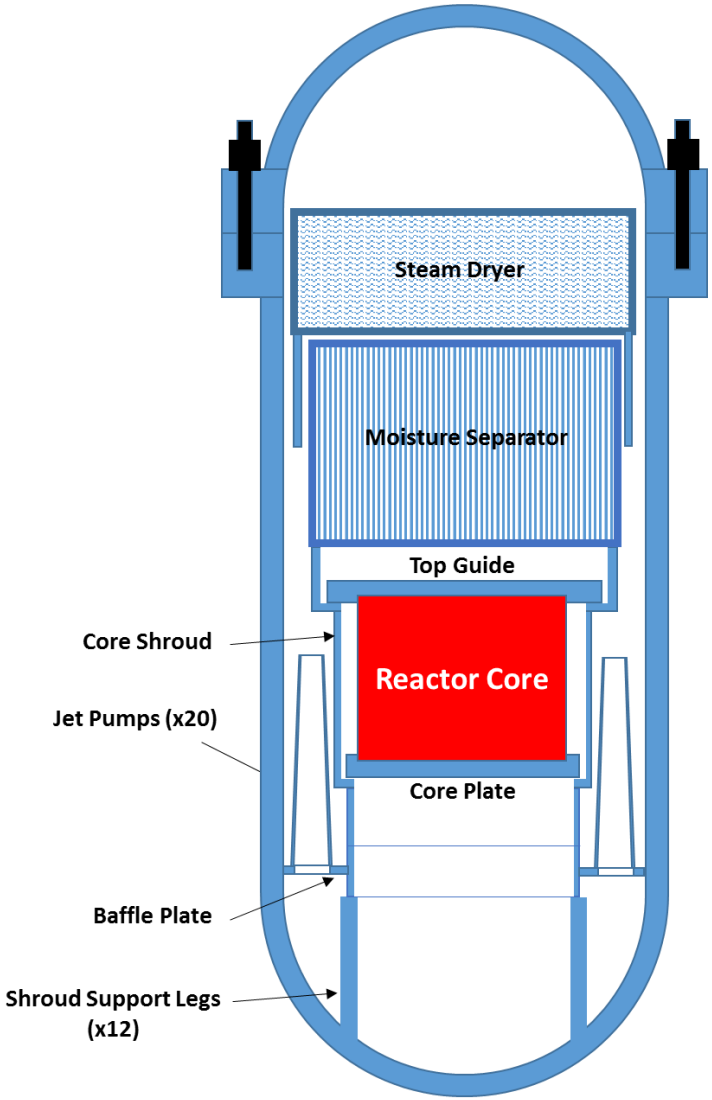
Core Debris retrieval to Cask loading

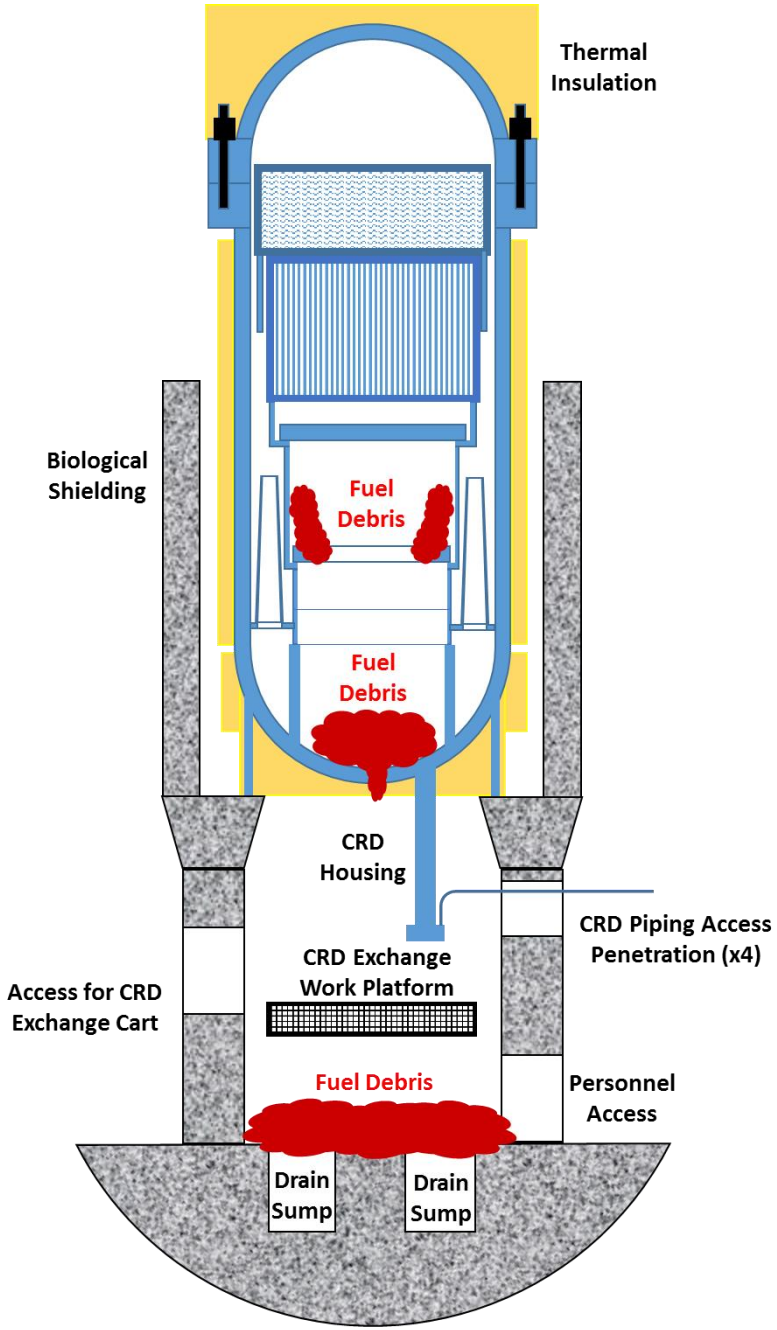


Air-Cooling – Not A Big Challenge

Heat Dissipation Mechanism

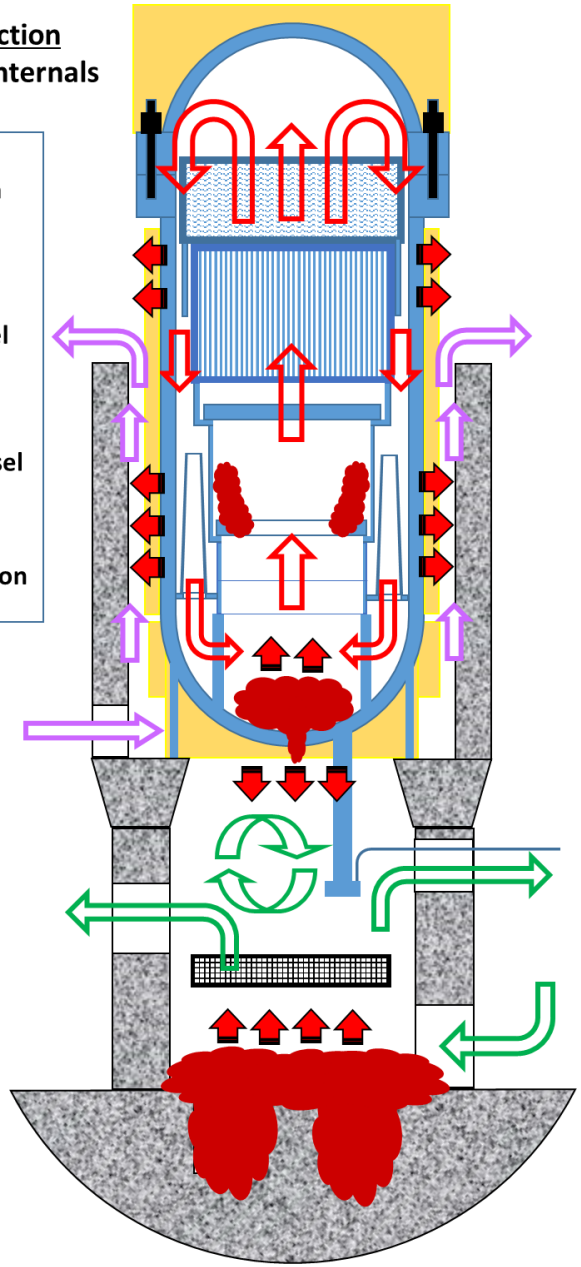
- **Conduction: Massive concrete structures with high density rebar surrounding Containment is a good "heat sink".**
- **Convection:**
  - **Potential local heat-up inside Pedestal region is prevented by air flow.**
  - **Heat from RPV is carried by air flow through annulus region between RPV and Biological Shielding and distributed entirely inside Containment.**
  - **"Air gap" between Containment and concrete shield can be a good passage for air flow. "Mist-injection" further improves efficiency.**
- **Radiation:**
  - **"Above Core Structures" (Moisture Separator and Steam Dryer) behave as "radiators" and minimize local heating inside RPV.**
  - **Drywell Head also behaves as "radiator".**
- **Escaped Heat Source: 10 to 15% heat source (radioactivity) already escaped from RPV to "Tank Farm".**


Steam Dryer
Moisture Separator
Top Guide
Core Shroud
Reactor Core
Jet Pumps (x20)
Core Plate
Baffle Plate
Shroud Support Legs
(x12)


Thermal
Insulation
Biological
Shielding
Fuel
Debris
Fuel
Debris
CRD
Housing
CRD Piping Access
Penetration (x4)
CRD Exchange
Work Platform
Access for CRD
Exchange Cart
Fuel Debris
Personnel
Access
Drain
Sump
Drain
Sump

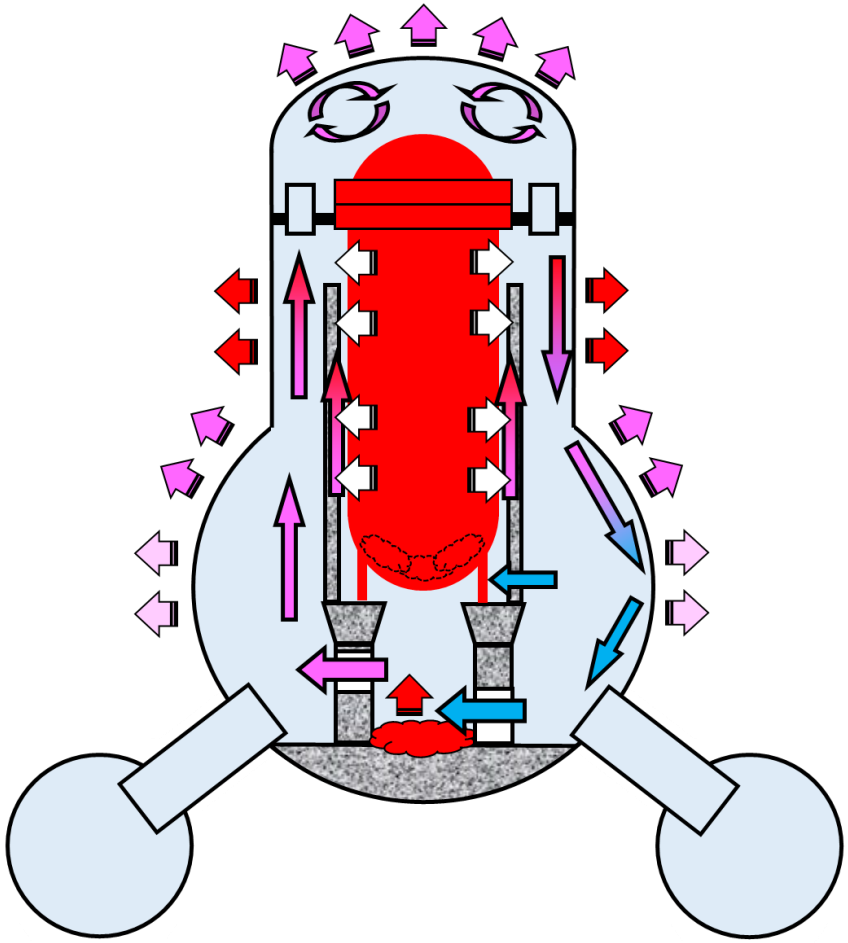
Radiation and Convection
(1) Reactor Vessel and Internals

- Heat Radiation from Fuel Debris
- Heat Convection inside Reactor Vessel
- Heat Convection around Reactor Vessel
- Heat Convection inside Pedestal Region

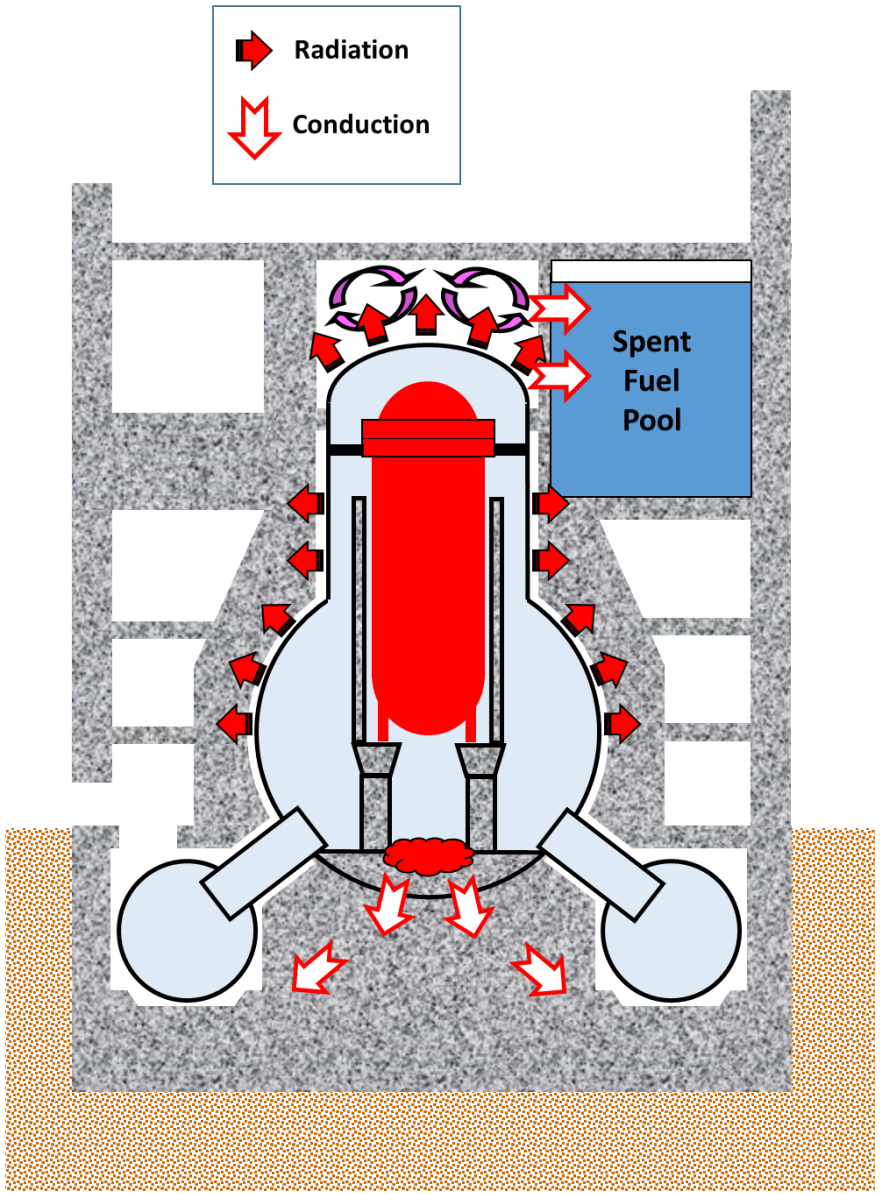


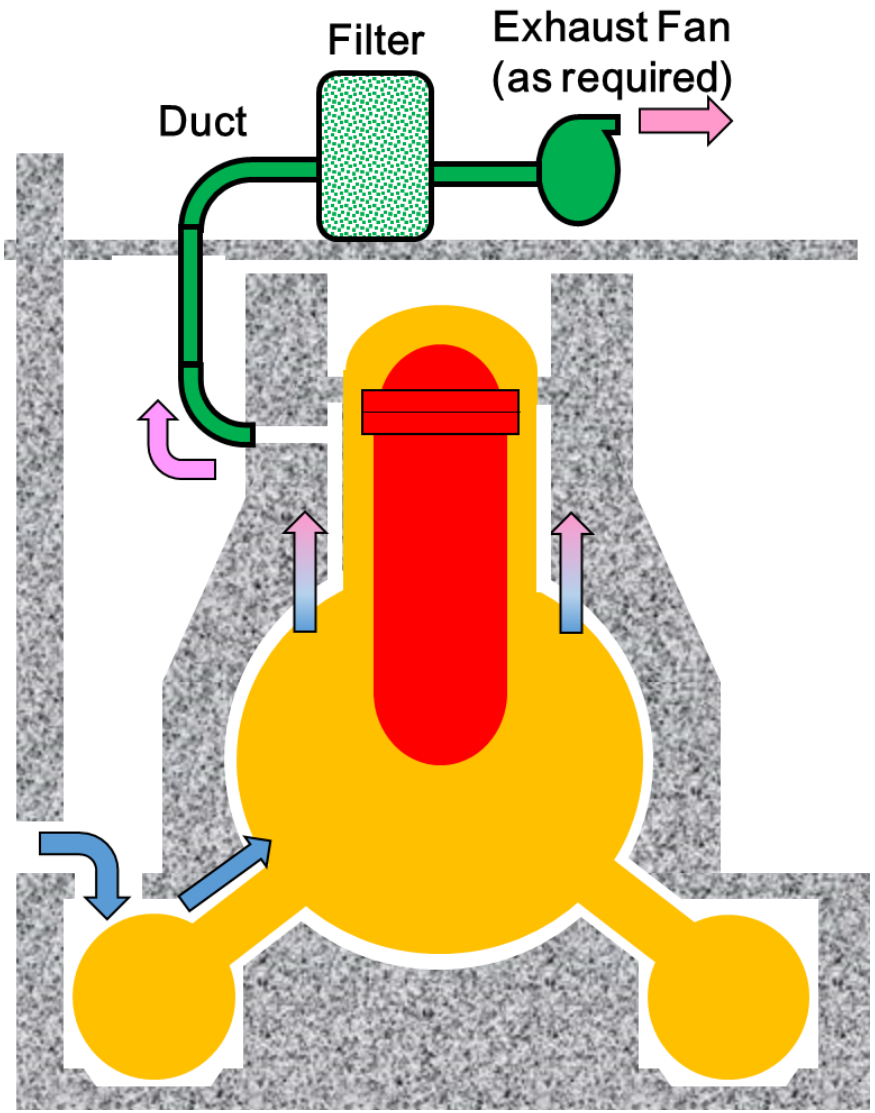
Radiation and Convection
(2) Primary Containment

- Heat Radiation from Fuel Debris
- Heat Convection inside Containment



Radiation and Conduction to Massive Heat Sink





Benefit of Mist Injection

Dry Air
12,300m³/h
30-deg.C

200kW Heater

Dry Air
80-deg.C

Heat Capacity (to heat up to 80-deg.C)

- 30-deg.C Dry Air = 58.7kJ/m³
- 30-deg.C Moistened Air = 562kJ/m³

30-deg.C Water
Enthalpy = 125.7 kJ/kg

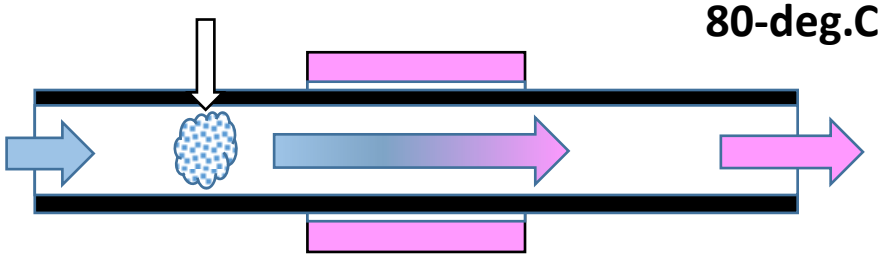
80-deg.C Steam
Enthalpy = 2643.0 kJ/kg

Required flow rate is
reduced by nearly 90% !

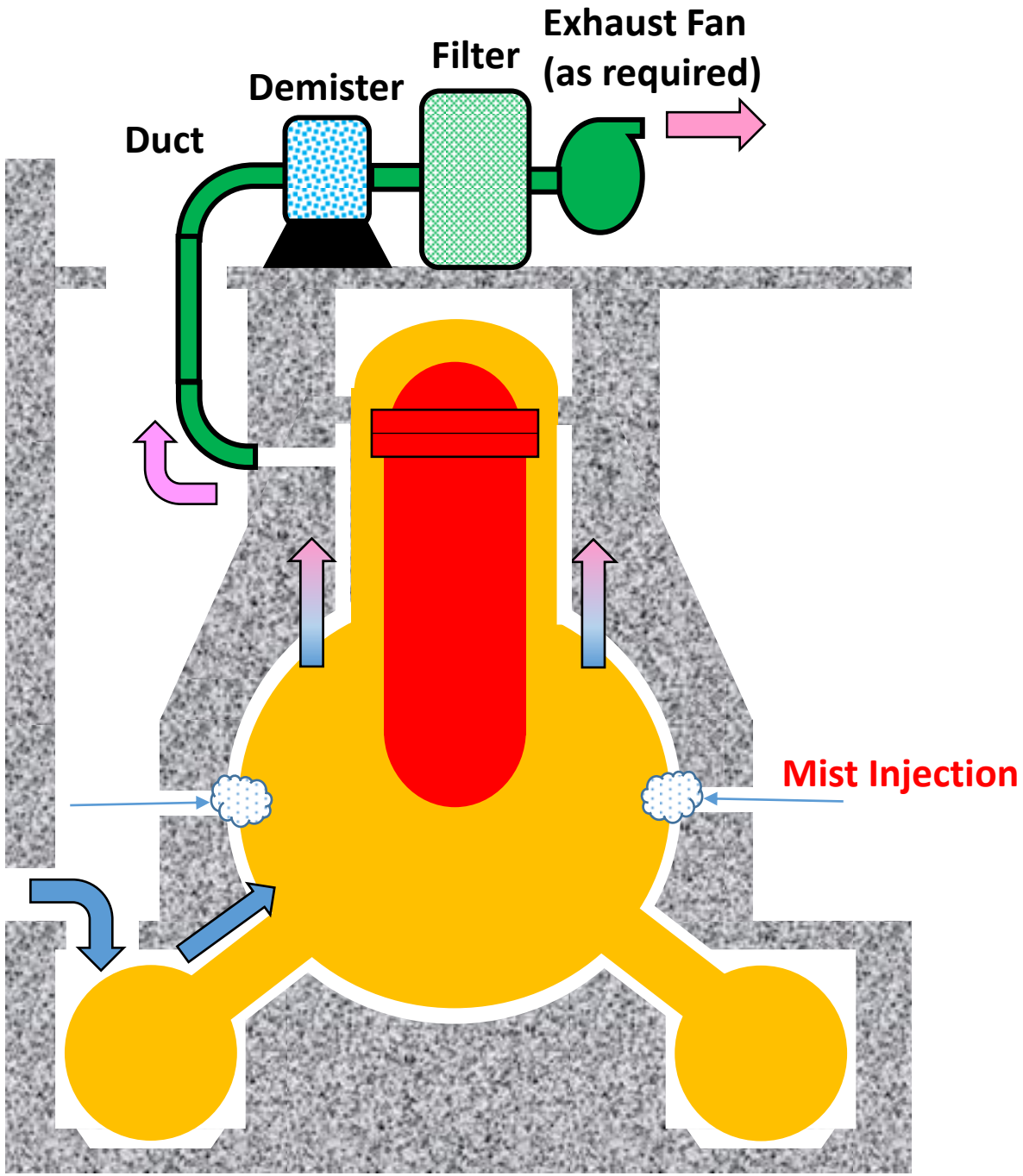
Mist Injection
200g/m³

RH 75~80% Air
80-deg.C

RH 50% Air
1,280m³/h
30-deg.C



200kW Heater


Exhaust Fan
(as required)
Filter
Demister
Duct
Mist Injection

Air-Cooling – Not A Big Challenge

Potential Structural Degradation

- **Containment is a self-standing steel structure.**
- **RPV is seismically supported in lateral direction by stabilizers via Biological Shielding which takes credit of only steel components (inner/outer plates and columns in between). Note**
- **RPV is vertically supported by Pedestal which has significant structural margin and typically does not depend on concrete as a load path. Note**
- **Potential thermal degradation of concrete does not challenge stability of RPV. Note**

Note: Plant-specific evaluation is still necessary.

Air-Cooling – Not A Big Challenge

Airborne Problem

- Cooling outside of Containment minimizes the chance of carry-over.
- Particle element: Standard HEPA filter is effective.
- Gaseous element: Potential generation of ruthenium tetroxide (RuO_4) is prevented by maintaining Containment inert with nitrogen.
- Air-Balance Control: Standard engineering practice is applicable.